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Methodology for Modeling 2-D Groundwater Motion in a Geographic Information System (GIS)

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INTRODUCTION

From the mid-1950's through the 1980's, the U.S. Department of Energy's Savannah River Site (SRS) produced nuclear materials for the weapons stockpile, for medical and industrial applications, and for space exploration. A legacy of this production is groundwater contamination located near previous production sites. This contamination is comprised mainly of heavy metals, organic degreasers, and radionuclides such as tritium. To monitor this contamination, a network of more than 1000 groundwater wells has been established across SRS.

As a result of this contamination, extensive remediation activities are ongoing at SRS. Modeling the 3-D flow and transport of groundwater to support these efforts is a time consuming and arduous task involving discretizing a model domain representing geological and hydrogeological surfaces, specifying appropriate boundary conditions, and calibrating the model to measured piezometric and potentiometric data. For SRS areas where the groundwater motion is essentially 2-D with negligible vertical gradients, a simplified modeling capability was developed in a GIS software framework providing the capability to simulate 2-D groundwater motion with results that could be obtained in hours, versus weeks or months often required for a full 3-D model.

DESCRIPTION

SRNL developed a 2-D groundwater flow modeling capability in GIS to facilitate rapid evaluation and analysis of groundwater flow in which vertical gradients are negligible. Advantages of this GIS simulation capability are the speed with which analyses can be completed, the ready availability of geologic data at SRS in GIS formats, and the fidelity of the simulation results to the underlying geologic information utilized by the model.

The GIS groundwater flow modeling methodology involves the following straightforward steps: (1) developing potentiometric or piezometric contours representing groundwater elevations, (2) using a gridding algorithm to develop a 3-D surface representing the groundwater elevation, (3) creating grids of hydraulic conductivity, aquifer thickness, and porosity for the region of interest, and (4) executing an ARC/INFO algorithm developed by SRNL to compute the groundwater motion across the 3-D elevation surface. Groundwater motion is computed separately for each aquifer being simulated.

SRS employs an extensive groundwater monitoring well network with wells sampled either on a quarterly or biannual basis and this information is easily accessible from a customized GIS interface. Once this groundwater elevation data is accessed and posted on a map, geosciences personnel can easily create elevation contours. Algorithms such as TOPOGRID (available within Arc/Info or ArcGIS) then may be used to make a 3-D surface representing the groundwater elevation based on the elevation contours. Likewise, geostatistical krigging and a myriad of other gridding algorithms also can be used to create these 3-D elevation surfaces. TOPOGRID is a particularly robust algorithm in that it was developed specifically for geosciences data and has the advantage of exactly honoring the groundwater elevation contours used as input. Figure 1 illustrates groundwater elevation contours and the resulting gridded elevation surface developed using TOPOGRID for the Crouch Branch Aquifer in the northwestern part of the Savannah River Site.

Once the groundwater contours and elevation surface are developed, grids representing the porosity, hydraulic conductivity, and aquifer thickness can be created using the same procedure described above. If limited data is available, these can be developed as unit grids representing a single property value.

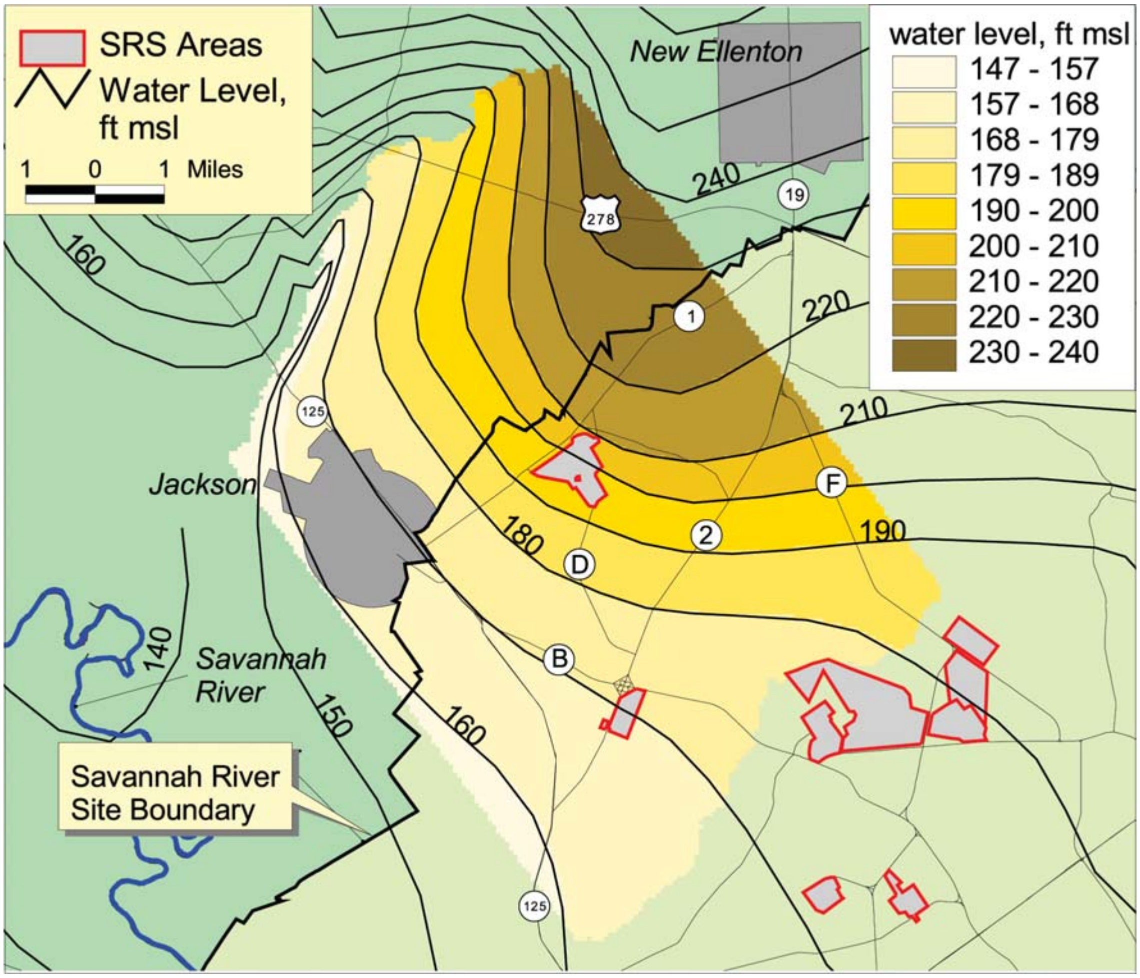

Figure 1. Groundwater Elevation Contours and resulting Gridded Elevation Surface for the Northwestern Savannah River Site for the Crouch Branch Aquifer.

The final step involved in computing the groundwater motion over the 3-D groundwater elevation surface is performed using an algorithm developed at SRNL to solve Laplace's equation for groundwater flow in 2-D. This is accomplished by creating a mesh of regularly spaced points over the region of interest using an extension developed for ArcView 3.2a. Once a GIS file containing these points is created, the groundwater flow algorithm can be executed with the points file and requisite grids as input to compute the groundwater particle tracks emanating from each point. Figure 2 illustrates particle track results for the Crouch Branch aquifer at SRS using the elevation surface from Figure 1 as input. Computing the particle paths is essentially equivalent to computing the Lagrangian of the particle through a potential field, in this case, the groundwater elevation potential.

RESULTS

The methodology described above has been utilized to evaluate the adequacy of the well monitoring network along the northwestern boundary of SRS to increase the confidence that water migrating across SRS boundary does not contain contaminants. Analyses such as this can now be accomplished in a matter of hours without the need for much more complex and expensive 3-D groundwater flow and transport models. Such rapid results facilitate the ability to run a myriad of parametric cases to more completely understand the groundwater flow system. Finally, since the groundwater elevation surface is an almost exact representation of the original elevation contours, this methodology has the added advantage of computing a very accurate 2-D flow field devoid of calibration errors and uncertainties that accompany more complex 3-D models.

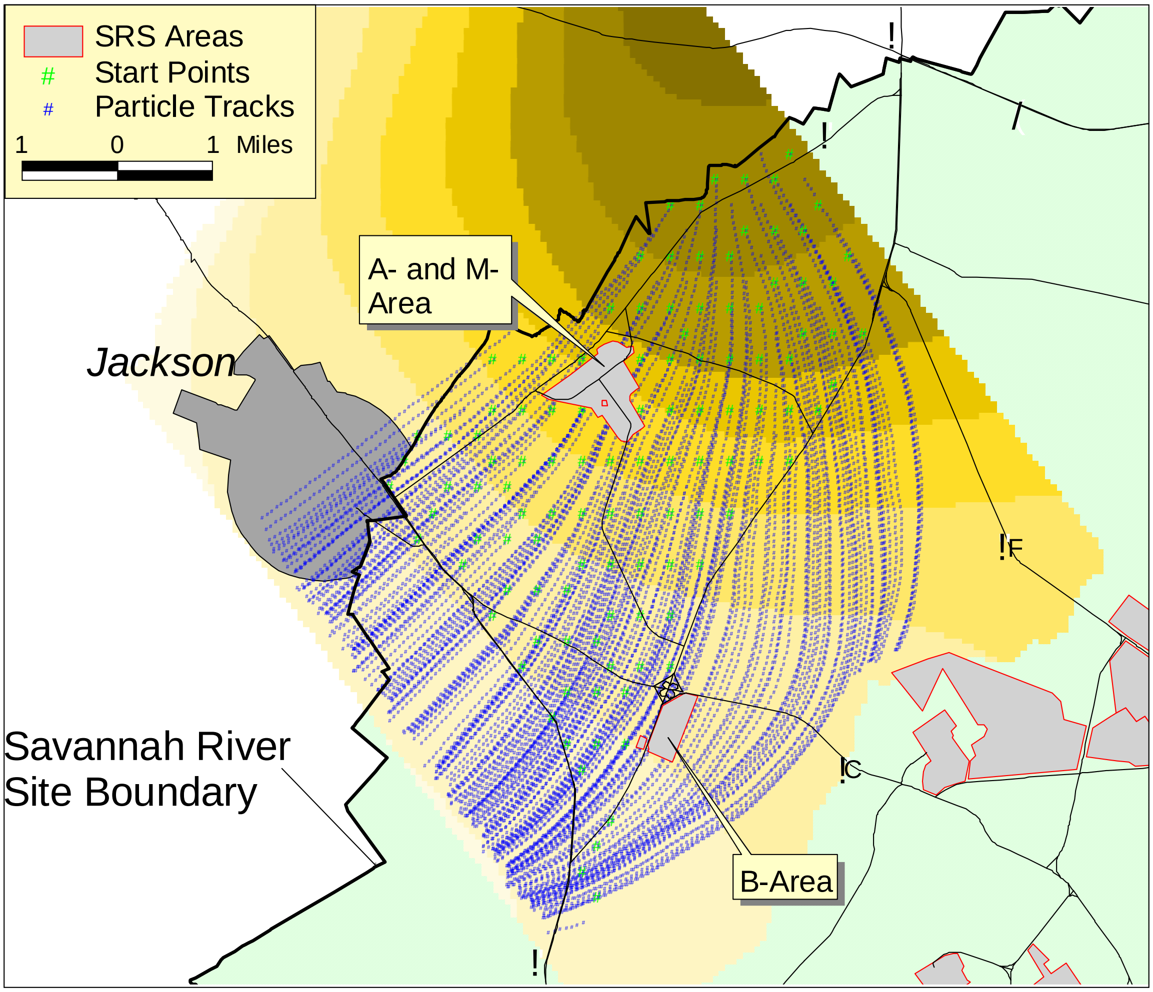

Figure 2. Groundwater Pathlines for the Crouch Branch Aquifer on the Northwestern Boundary of the Savannah River Site.